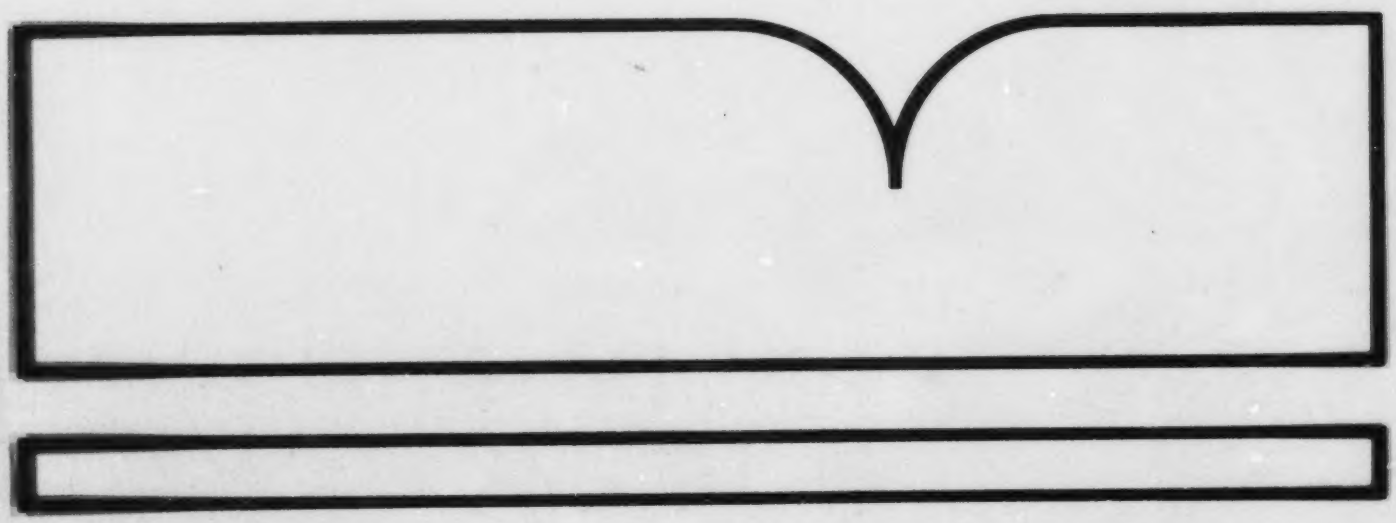
PB86-208550

Nutrient Enrichment of Chesapeake Bay and Its Impact on the Habitat of Striped Bass: A Speculative Hypothesis

(U.S.) Environmental Protection Agency
Annapolis, MD

1985



U.S. Department of Commerce
National Technical Information Service

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. REC
EPA/600/J-85/422		PB86-208550

4. TITLE AND SUBTITLE	5. REPORT DATE
NUTRIENT ENRICHMENT OF CHESAPEAKE BAY AND ITS IMPACT ON THE HABITAT OF STRIPED BASS: A SPECULATIVE HYPOTHESIS (Journal Version)	1985
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
K.S. Price*, D.A. Flemer, J.L. Taft**, G.Mackiernan, W. Nehlsen, R. Biggs*, N. Burger***, & D. Blaylock***	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
*University of Delaware, Lewes, Deleware; **Harvard University Herbaria, Cambridge, MA; ***Institute of Statistical & Mathematical Modeling, University of West Florida, Pensacola, FL 32504.	11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Chesapeake Bay Program Office of Research and Development U.S. Environmental Protection Agency Annapolis, MD 21401	14. SPONSORING AGENCY CODE EPA/600/4

15. SUPPLEMENTARY NOTES

REF: Transactions of the American Fisheries Society, 114:97-106, 1985

16. ABSTRACT

Stocks of striped bass Morone saxatilis have declined in the Chesapeake Bay system over the last decade. We present evidence for the working hypothesis that the decline has resulted, in part, from loss of deep-water habitat for adults, caused by limiting concentrations of dissolved oxygen that are related, in turn, to nutrient enrichment and greater planktonic production. A related hypothesis is that changes in the near-shore habitat for juvenile striped bass, involving severe declines in submerged aquatic vegetation due to nutrient-driven planktonic shading, also have contributed to the decline of striped bass. Nutrients (nitrogen and phosphorus) and chlorophyll a, an indicatior of phytoplankton biomass, have increased in many areas of the bay and tributaries over the past 20 to 30 years. These trends are qualitatively correlated with greater deoxygenation of the deep channel in the mid and upper bay. During the late 1970s, summer oxygen concentrations as low as 2 ml/liter approached to within 7-8 m of the surface, allowing water stressful to striped bass to intrude onto shoal areas of the bay. The volume of Chesapeake Bay bottom waters containing 0.5 ml O_2/liter or less was about 15 times greater in July 1980 than in July 1950. The combination of the expanding hypoxic pool and summer temperatures above preferred levels for adult striped bass may contribute to an "oxygen-temperature squeeze" that forces adults onto shoal areas of the bay or out of the upper bay.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	11
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	

EPA/600/J-85/422
JOURNAL ARTICLE

Transactions of the American Fisheries Society 114:97–106, 1985

Nutrient Enrichment of Chesapeake Bay and Its Impact on the Habitat of Striped Bass: A Speculative Hypothesis

KENT S. PRICE,[1] DAVID A. FLEMER, JAY L. TAFT,[2]
GAIL B. MACKIERNAN, WILLA NEHLSEN, ROBERT B. BIGGS,[1]
NED H. BURGER,[3] AND DEWEY A. BLAYLOCK[3]

Chesapeake Bay Program, United States Environmental Protection Agency
839 Best Gate Road, Annapolis, Maryland 21401

Abstract

Stocks of striped bass *Morone saxatilis* have declined in the Chesapeake Bay system over the last decade. We present evidence for the working hypothesis that the decline has resulted, in part, from loss of deep-water habitat for adults, caused by limiting concentrations of dissolved oxygen that are related, in turn, to nutrient enrichment and greater planktonic production. A related hypothesis is that changes in the near-shore habitat for juvenile striped bass, involving severe declines in submerged aquatic vegetation due to nutrient-driven planktonic shading, also have contributed to the decline of striped bass. Nutrients (nitrogen and phosphorus) and chlorophyll *a*, an indicator of phytoplankton biomass, have increased in many areas of the bay and tributaries over the past 20 to 30 years. These trends are qualitatively correlated with greater deoxygenation of the deep channel in the mid and upper bay. During the late 1970s, summer oxygen concentrations as low as 2 ml/liter approached to within 7–8 m of the surface, allowing water stressful to striped bass to intrude onto shoal areas of the bay. The volume of Chesapeake Bay bottom waters containing 0.5 ml O_2/liter or less was about 15 times greater in July 1980 than in July 1950. The combination of the expanding hypoxic pool and summer temperatures above preferred levels for adult striped bass may contribute to an "oxygen–temperature squeeze" that forces adults onto shoal areas of the bay or out of the upper bay. Many of these shoal areas now lack suitable cover for juvenile striped bass and their prey. Strong intraspecific competition among striped bass may be occurring there.

Striped bass *Morone saxatilis* populations have declined for the past decade over much of their east-coast range, especially in Chesapeake Bay (Fig. 1). The decline appears to be related to a failure in year classes during the entire period since the last dominant one in 1970, which brought peak landings in 1973. The importance of the striped bass fishery to Chesapeake Bay and the effects of its decline elsewhere along the east coast has led to increased attention to this species by the United States Congress, state resource managers, and the research community.

As referenced in this issue by Coutant (1985), numerous factors may contribute to the decline of striped bass stocks, and this makes it difficult to assess the relative importance of various causes. As part of an effort to sort out meaningful explanations for the decline in the fishery, we present here an analysis of the role of nutrient enrichment in Chesapeake Bay. The working hypothesis is that nutrient enrichment has altered ecological conditions for striped bass in two ways: (1) loss of habitat for adult fish has occurred largely through reductions in dissolved oxygen concentrations, causing an "oxygen–temperature squeeze" on the fish; and (2) loss of habitat for juvenile fish has occurred through reductions in submerged aquatic vegetation.

In addressing the speculative hypothesis regarding the role of nutrient enrichment we must test the following components of our hypothesis.

(1) Nutrient loading and ambient nutrient values in upper to middle Chesapeake Bay are increasing with time and have increased particularly since 1970.

(2) There is a linkage between increased nutrient loading and worsened deoxygenation in the Chesapeake Bay.

(3) There is a linkage between increasing nu-

[1] Principal affiliation: College of Marine Studies, University of Delaware, 700 Pilottown Road, Lewes, Delaware 19958.

[2] Principal affiliation: Harvard University Herbaria, 22 Divinity Avenue, Cambridge, Massachusetts 02138.

[3] Principal affiliation: Institute of Statistical and Mathematical Modeling, University of West Florida, Pensacola, Florida 32504.

NTIS is authorized to reproduce and sell this report. Permission for further reproduction must be obtained from the copyright owner.

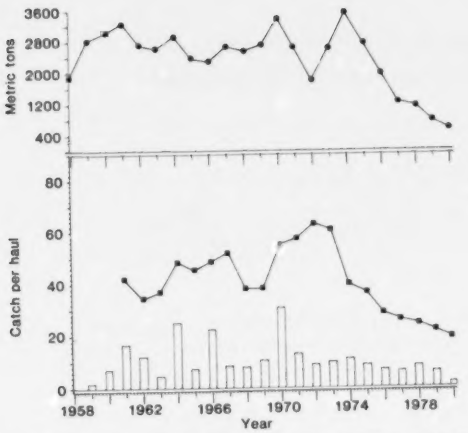


FIGURE 1.—*Trends in landings (metric tons) of striped bass for Chesapeake Bay (USEPA 1983), and in relative abundance (juvenile index, catch per seine haul) of young-of-the-year striped bass in Maryland (bars: annual values, after Boone 1980; squares: moving 4-year means).*

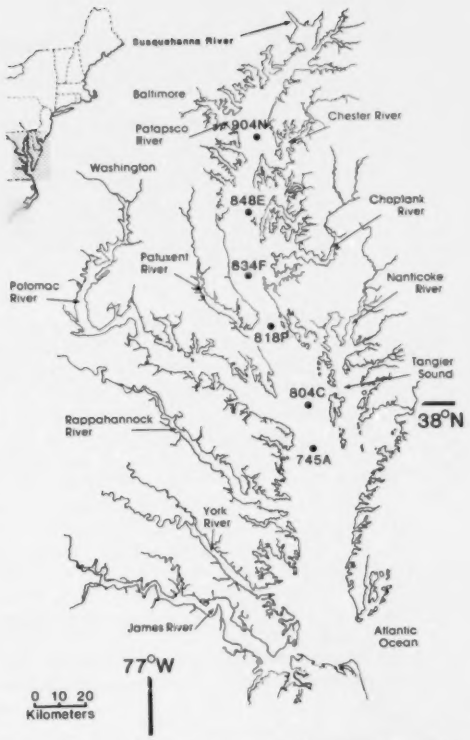


FIGURE 2.—*Map of Chesapeake Bay showing major tributaries and station locations (numbered dots) for oxygen and temperature measurements.*

trient concentrations and the decline in submerged aquatic vegetation in the Chesapeake Bay.

(4) The worsening deoxygenation in the Chesapeake Bay is creating an oxygen–temperature squeeze on adult striped bass.

(5) The decline of submerged aquatic vegetation has reduced available habitat for juvenile striped bass in Chesapeake Bay, particularly since 1970.

(6) The decline in striped bass is related to an increase in the oxygen–temperature squeeze on adult striped bass and a decline in habitat provided by submerged aquatic vegetation for juvenile striped bass.

The cogent aspects of the striped bass life cycle in Chesapeake Bay that bear on the hypothesis of this paper are presented in Lippson (1973) and Setzler et al. (1980). Striped bass spawn in fresh or nearly fresh waters of tributary rivers in April, May, and early June. After the eggs hatch, the young larvae move out of fresh water into low-salinity nursery areas, still within the rivers. As they grow, young striped bass gradually move downstream, concentrating along warm shoal areas of the bay and rivers to feed during their first summer. Adult striped bass tend to be found in deeper cooler water of the bay and are highly susceptible to temperature changes. Thus, seasonal migrations and thermal niche partitioning segregate various sizes of striped bass, the youngest fish tending to be up-estuary and around the bay margins, and the older fish (2+ years) tending to be in the middle portions of the bay.

Although an oxygen–temperature squeeze could have a debilitating effect on the condition of adult striped bass (Coutant 1985), the effect would not be expressed as a decline in successful year classes unless spawning populations were depressed to a very low level, because the striped bass is believed to demonstrate density-independent recruitment (Cooper and Polgar 1981).

Methods

Analytical methods for deriving trends and establishing correlations are described in considerable detail for each component of the hypothesis in the following literature.

(1) Chesapeake Bay nutrient trends: Heinle et

al. (1980); USEPA (1983). In a subsequent section, trends in nutrient enrichment will be related to concentrations of dissolved oxygen. Data are available to characterize nutrient and chlorophyll-*a* trends from 1950 to 1980 in the upper mainstem of Chesapeake Bay from the mouth of the Patapsco River north 20 kilometers (Fig. 2). These data are maintained in the Chesapeake Bay Program computer data base.

Chlorophyll *a* is considered a useful measure of phytoplankton biomass. Data used in this analysis are "uncorrected" for chlorophyll-*a* degradation products because comparative data from before about 1968 could not be used otherwise. Total nitrogen and phosphorus concentrations are better indicators of trophic conditions than the respective soluble fractions because the latter are kept low by plant uptake. Annual nutrient and chlorophyll-*a* trends are based on the following criteria: at least three observations of each variable were needed in each month for each year to calculate a monthly mean; a minimum of two monthly means was necessary to calculate a seasonal mean; and two seasonal means were needed to produce an annual mean. This procedure ensures at least a minimum adequacy of data to characterize each annual mean.

(2) Nutrient–O_2 linkage in Chesapeake Bay: Taft et al. (1980); USEPA (1983); Officer et al. (1984). Methods for calculating the volume of water with O_2 concentrations of 0.5 ml/liter or less and 2.0 ml/liter or less are based on the topography of the bay bottom and the interpolated depth of the isopleth of the oxygen concentration in question; a level projection of the top of each layer laterally over the bay is assumed (described in detail in USEPA 1983).

(3) Nutrient–submerged aquatic vegetation linkage in Chesapeake Bay: Kemp et al. (1983); USEPA (1983).

(4) Oxygen–temperature squeeze on striped bass in Chesapeake Bay: Coutant (1985).

(5) Decline of submerged aquatic vegetation: Kemp et al. (1983); USEPA (1983).

(6) Trends in the decline of striped bass as measured by landings and surveys of young of the year (juvenile index): Boone (1980); USEPA (1983). Goodyear (1985, this issue) has shown that 83% of the variation in striped bass landings could be accounted for by the juvenile indexes 2, 3, 4, and 5 years prior to the landings for the period 1963–1983; age-3 and -4 fish dominated catches during 1964–1973, age-2 and -3 fish thereafter. The 4-year moving mean of the juvenile index for 1958–1980 (Fig. 1) is positively correlated with landings (Pearson $r_s = 0.71$; $N = 20$; $P < 0.05$).

In an attempt to establish correlative relationships among environmental variables and year-class success of striped bass, as estimated separately by juvenile indexes and Chesapeake Bay landings, the following relationships were tested by Pearson correlation analysis:

(a) July volumes of, and bottom areas covered by, Chesapeake Bay water having O_2 concentrations of 0.5 ml/liter or less and 2.0 ml/liter or less versus aggregated juvenile indexes lagged 0–5 years in annual increments;

(b) each of the July environmental variables in (a) versus aggregated striped bass landings lagged 0–5 years in annual increments;

(c) annual mean flow of the Susquehanna River at Harrisburg, Pennsylvania, versus lagged juvenile indexes and lagged landings. The Susquehanna River is the principal northern tributary of the bay (Fig. 2); during average rainfall conditions, it contributes approximately 50% of the bay's freshwater discharge, 40% of the nitrogen load, and 21% of the phosphorus load (USEPA 1983).

The data used in the analysis of the oxygen–temperature squeeze in the mainstem of the bay were collected by the Chesapeake Bay Institute of Johns Hopkins University from 1950 to 1980 and were made available to the Chesapeake Bay Program. The assessment focused on the deep channel area, which lies in the region bounded upstream near the Patapsco River, 39°5′N latitude (station 904N), and seaward in the region of the bay near Reedville, Virginia, approximately 37°45′N latitude (station 745A) (Fig. 2). Channel depths frequently reach 30 m and occasionally reach 40 to 55 m. This region is partially stratified and a halocline typically occurs at depths between 8 and 14 m.

Kaumeyer and Setzler-Hamilton (1982) summarized oxygen tolerances for Chesapeake Bay striped bass. A concentration of 0.5 ml/liter O_2 causes death of larvae, juveniles, and adults; concentrations of 2.9–3.0 ml/liter (44% oxygen saturation) cause avoidance and stress behavior by all three life stages. Coutant (1985) indicates that striped bass adults require about 2.0 ml/liter O_2 to avoid respiratory stress. Therefore, we examined the volume of water from which striped bass adults likely would be excluded by three

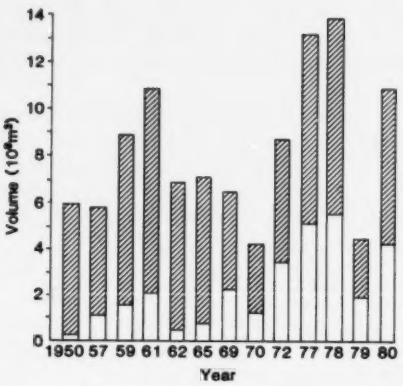


FIGURE 3.—*Volumes of water in Chesapeake Bay over the deep channel containing dissolved oxygen concentrations of 2.0 ml/liter or less (total bars) and 0.5 ml/liter or less (open portions of bars) (USEPA 1983). Values are for selected years from 1950 to 1980 based on summer conditions typically represented by July or August cruises. (The 1965 value for 0.5 ml/liter is extrapolated from the 0.8-ml/liter level.)*

processes: by death, 0.5 ml/liter O_2; by respiratory stress, 2.0 ml/liter O_2; and by behavioral avoidance, 3.0 ml/liter O_2. Coutant (1985) suggests a thermal niche preference for adult striped bass of 18–21 C and higher preferences, up to 26 C, for successively smaller individuals. For the purposes of testing our hypothesis, we selected 22 C as the upper threshold of avoidance behavior by adult striped bass in Chesapeake Bay.

Data on Susquehanna River flow were obtained from the United States Geological Survey. Data on the occurrence of submerged aquatic vegetation were obtained from the United States Fish and Wildlife Service and the Maryland Department of Natural Resources.

Results

Based on a 30-year O_2 record for Chesapeake Bay (Fig. 3), Officer et al. (1984) concluded that the summer volume of water having oxygen concentrations less than 0.5 ml/liter O_2 increased approximately 15 times between 1950 and 1980. The pattern of increase in the volume of water having oxygen concentrations less than 2.0 ml/liter O_2 is not as clearly defined, but this volume was less than 6×10^9 m^3 in 1950, 1957, 1970, and 1979 but greater than 10×10^9 m^3 in 1961, 1977, 1978, and 1980 (Fig. 3). By this measure, then, summer hypoxia has been more prevalent since 1971 than before that year.

There were only eight significant ($P \leq 0.05$) Pearson correlation coefficients (r_s) for relationships between the juvenile index or landings and hydrological variables:

Variable	Lag (years)	N	r_s
Juvenile index			
≤2 ml O_2/liter			
Volume	5	7	0.67
Area	5	7	0.63
Landings			
≤2 ml O_2/liter			
Volume	3	9	−0.64
Area	3	9	−0.64
≤0.5 ml O_2/liter			
Volume	0	12	−0.50
Area	2	10	−0.59
Susquehanna flow	4	8	−0.91
	5	7	−0.95

In summary then, larger volumes and areas covered by 0.5 ml O_2/liter (or lower concentration) may have contributed to declines in landings during the year of the occurrence and 2 years later. Larger volumes and areas covered by 2.0 ml O_2/liter (or lower concentration) may have contributed to declines in landings 3 years after the occurrence but to more successful year classes 5 years later.

Correlations of the annual mean flow of the Susquehanna River did not show significant relationships with the aggregated juvenile index for striped bass such as Mihursky et al. (1981) have shown in the Potomac River. However landings lagged 4 and 5 years showed strong inverse relationships with Susquehanna River flow. Thus high Susquehanna River flows may contribute to declines in landings 4 and 5 years after the occurrence.

Oxygen Demand and Nutrients

One principal result of nutrient enrichment that is of concern to managers is the oxygen demand created by increased production of organic material. Therefore, the criteria for describing the current condition of the Chesapeake Bay system are related to nutrient levels and corresponding potential oxygen demand. For the simplest case, planktonic organic material and its oxidation can

be represented, after Richards (1965), by the following formula:

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2$$
organic material
$$\rightarrow 106CO_2 + 122H_2O + 16NHO_3 + H_3PO_4$$
remineralized nutrients

The coefficients in this relationship are multiplied by the atomic weights of the elements to obtain the masses involved. That is, for nitrogen, 16 times the atomic weight of 14 gives 224 mass units, and for oxygen, 138 times 32 gives 4,416 mass units. Converted to milligrams, planktonic organic material containing 0.224 mg nitrogen would require 4.42 mg oxygen for complete degradation, giving a ratio of 19.7 mg oxygen for every 1 mg nitrogen.

This relation between organic material and the oxygen required for its complete mineralization was used to construct a table of potential oxygen concentrations and organic material concentrations expressed in terms of carbon, nitrogen, and phosphorus (Table 1). The table is entered with a nutrient concentration value: for example, 0.035 mg phosphorus per liter represents a potential oxygen demand by organic material of 5 mg. Thus a saturation dissolved oxygen concentration of 7 mg/liter would be reduced by 5 mg to 2 mg/liter if all of the organic material associated with 0.035 mg P/liter were oxidized. The potential oxygen demand is expressed as mg rather than mg/liter because, in some cases, the potential demand is much greater than the actual saturation oxygen concentration.

If this approach is carried further, it can be seen that a total nitrogen concentration of 0.75 mg/liter would have a potential oxygen demand of 15 mg oxygen/liter. However, expected oxygen saturation values at salinities and temperatures typical of deep upper-bay waters are only 12.5 mg/liter oxygen in March and 9.5 mg/liter in May. Thus, if total nitrogen concentrations are maintained near 0.75 mg/liter in the upper bay, the potential oxygen demand exceeds the available oxygen.

This simple approach does not account for either reaeration of the water from the atmosphere or steady accumulation of organic material in the deep water (which can increase oxygen demand). Reaeration of the water column is a function both of diffusion and mixing; aeration of bottom water is reduced when strong vertical stratification exists, as occurs during warm months in much of the bay. The net result of these interacting processes can be illustrated by the 1980 data set for Chesapeake Bay: deep-water oxygen concentrations were about 10 mg/liter (7.0 ml/liter) in March and zero in May 1980 at all sampled depths below 11 m (Officer et al. 1984). Of the total oxygen loss, a decrease of 3 mg/liter was caused by temperature and salinity effects on oxygen solubility, and the remaining 7 mg/liter was due to biological and chemical oxidation reactions. If we apply the relationship outlined in Table 1, this 7 mg/liter oxygen loss is due to the oxidation of organic material containing 0.35 mg/liter nitrogen.

TABLE 1.—*Relation between organic material, nutrients, and potential oxygen demand.*

Organic material oxidized (mg/liter)			Potential oxygen demand (mg)
C	N	P	
0.28	0.05	0.007	1
1.40	0.25	0.035	5
2.80	0.50	0.070	10
4.20	0.75	0.105	15
5.60	1.00	0.140	20

The USEPA (1983) has used an index based on annual means of total nitrogen and total phosphorus for 1950–1980 to show that northern Chesapeake Bay and upper portions of the tributaries have relatively high nutrient concentrations and that, in most areas, nutrient enrichment is occurring. Chlorophyll concentrations exhibit a pattern in Chesapeake Bay similar to that of nutrients. Specifically, in the upper bay north of the Patapsco River (Fig. 2), annual average concentrations of total nitrogen, total phosphorus, and chlorophyll *a* have approximately doubled during the period 1965–1980 (Fig. 4). By 1971, concentrations of total nitrogen and total phosphorus exceeded the values (0.50 mg N/liter; 0.070 mg P/liter) estimated to create an oxygen demand exceeding available oxygen (Fig. 4; Table 1).

The concentration of dissolved oxygen in deep water begins to decline in Chesapeake Bay in February or March and is accelerated by increased salinity stratification related to the Susquehanna spring freshet (Taft et al. 1980). The

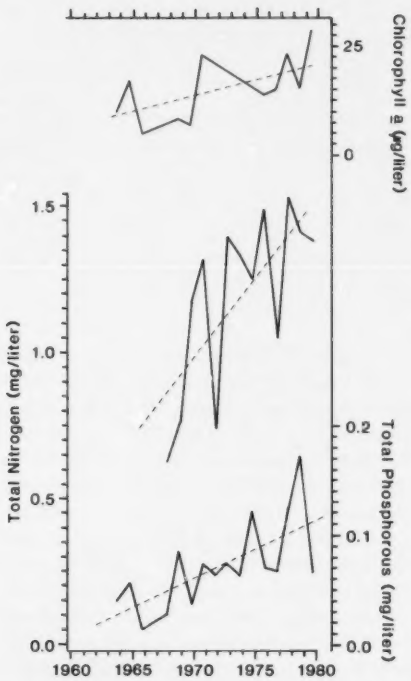


FIGURE 4.—*Annual trends of chlorophyll* a *and key nutrients in the northernmost regions of the Chesapeake Bay: annual values (solid lines) and regressions (dotted lines).*

22-C isotherm crosses the 2.0-ml/liter oxygen isopleth generally during June and remains below it through October when mixing processes restore oxygen concentrations to levels above 5 ml/liter through the winter (Officer et al. 1984; Wagner 1984).

Extent of Hypoxic Conditions

Although Newcombe and Horne (1938) and Newcombe and Lang (1939) observed brief episodes of low oxygen in the deep waters of Chesapeake Bay as far back as the 1930s, hypoxia has become more widespread and of longer duration in recent years (Officer et al. 1984).

The area affected by hypoxia extends from the vicinity of Baltimore to the mouth of the Rappahannock River (Fig. 2). The total volume of water that could become severely hypoxic (less than 0.5 ml/liter O_2) is approximately defined by bottom topography and halocline depth (approximately 12 m) and is calculated to be about

TABLE 2.—*The interpolated depth (m) of the 3-ml/liter O_2 isopleth in Chesapeake Bay compared to the temperature at that depth during July.*[a]

	Station 848E		Station 804C	
Year	Depth of 3-ml/liter O_2 isopleth (m)	Temperature (C)	Depth of 3-ml/liter O_2 isopleth (m)	Temperature (C)
1950	11	23.9	11	23.8
1957	11	25.7	11	26.0
1959	11	23.9	8	25.0
1961	8	24.9	9	23.7
1962	11	23.9	8	25.1
1965	6[b]	21.7[b]	12[c]	20.6[c]
1969	8[b]	24.2[b]	14	26.0
1970	6[b]	24.6[b]	10	25.0
1979	12	21.4	12	21.7
1980	12	23.7	6	26.6

[a] Source: Chesapeake Bay Institute data reports.
[b] Station 904N.
[c] Station 745A.

6.0×10^9 m^3. In July 1977, 1978, and 1980 nearly all of this potential anoxic volume contained low dissolved oxygen, most of it anoxic (Fig. 3). In 8 of 10 years for which there are appropriate data in the period 1950–1980, the 22-C isotherm dropped below the 3-ml/liter oxygen isopleth by July at particular sampling stations (Table 2); typically, it also dropped below the 2-ml/liter isopleth by this time in much of the bay (Fig. 5). The data on the volume of hypoxic water (Fig. 3) do not by themselves provide conclusive evidence of an historical increase in the low-oxygen problem, due in part to a low sampling frequency. However, when coupled with the demonstrated increase in ambient nutrient concentrations (Fig. 4) and the inferred increase in oxygen demand, the evidence is somewhat more compelling. In addition, two of us (Biggs and Price) have collected anecdotal evidence that, since 1965, blue crab (*Callinectes sapidus*) and finfishermen have had to set their pots and nets progressively closer to shore in shallower water in order to maintain satisfactory catches in the summer. During summer 1982, no blue crabs were caught in water deeper than 4 m. Carpenter and Cargo (1957) reported that oxygen concentrations below 0.5 ml/liter are lethal to blue crabs; those below 1.8 ml/liter cause stress behavior by the animals. In past years, male blue crabs hibernated in deepwater muds. They now hibernate in shallow water. We believe this evidence supports the concept that the hypoxic water mass

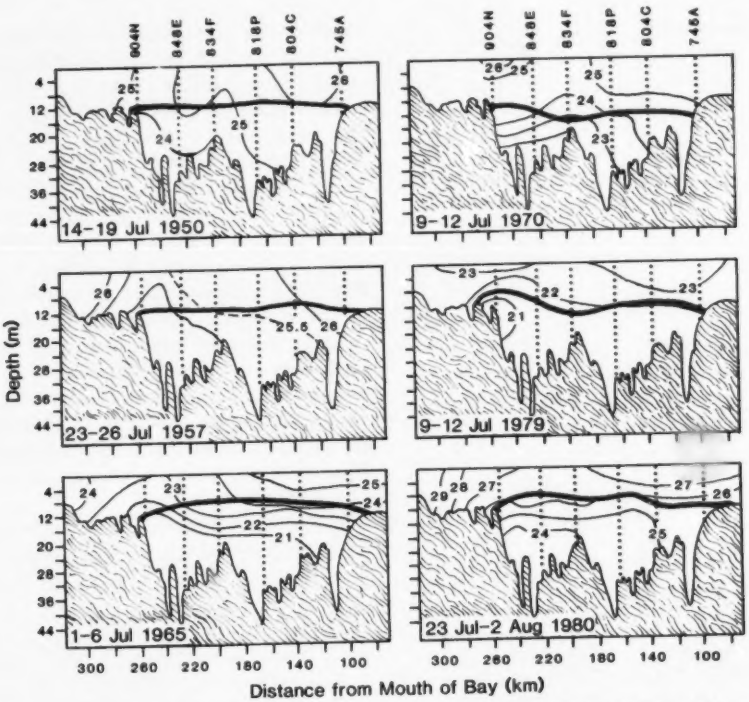


FIGURE 5.—*Temperature (C) profiles and 2.0-ml/liter dissolved oxygen isopleths (heavy solid lines) for selected years along the north–south channel of Chesapeake Bay in Maryland during midsummer, 1950–1980 (after USEPA 1983). Station numbers at the top of the figure correspond to those of Fig. 2.*

and its biological effects are becoming more extensive with time.

Submerged Aquatic Vegetation

In Chesapeake Bay, a major loss of submerged aquatic vegetation has continued since the mid 1960s, involving both native and exotic species (Fig. 6; Kemp et al. 1983). A survey of submerged aquatic vegetation (0–2 m depth) at 644 stations is conducted annually by the Maryland Department of Natural Resources and the United States Fish and Wildlife Service; 28.5% of the stations were vegetated in 1971, 10.5% in 1973, and only 5% in 1981 (Fig. 6). In general, statistical analyses show that abundance of submerged aquatic vegetation is inversely related to nutrient and chlorophyll-*a* concentrations. These results tend to support conclusions, based on experients, that link the recent loss of bay vegetation to increases in nutrient enrichment and ultimately to light stress due to increased phytoplankton and epiphyte growths (Kemp et al. 1983; USEPA 1983). Infaunal and fish communities of grass beds are more abundant and diverse than those in adjacent unvegetated areas (Orth 1977), and shorezone fish generally prefer naturally vegetated bottoms over bare bottoms (Briggs and O'Conner 1971). Orth and Heck (1980) found that striped bass ranked 18th in abundance of 48 species collected in Chesapeake Bay eelgrass meadows. Fish consumed by striped bass, *Syngnathus fuscus, Anchoa mitchilli, Bairdiella chrysura,* and *Menidia menidia* (Schaefer 1970), ranked second, third, fourth, and fifth in abundance, respectively. Among these, *Anchoa mitchilli* and *Menidia menidia* have declined during the 1970s in upper Chesapeake Bay, as measured in juvenile finfish surveys by the Maryland Department of Natural Resources (Boone 1980; USEPA 1983).

Discussion

The evidence suggests that nutrient loading in Chesapeake Bay is contributing to a growing pool of low-oxygen water ($\leq$2.0 ml/liter O_2 from May

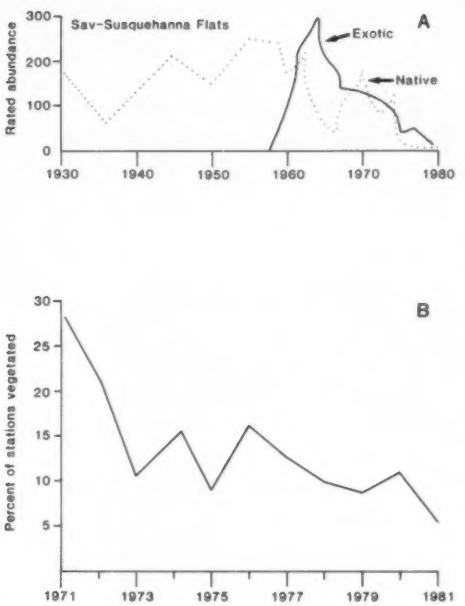


FIGURE 6.—*Trends in (A) submerged aquatic vegetation (SAV) abundance in upper Chesapeake Bay, 1958–1976 (after Kemp et al. 1983), and (B) percent occurrence of submerged aquatic vegetation in the Maryland part of the bay, 1971–1981 (after USEPA 1983).*

to October) that now affects at least 40% of the aqueous volume over an area about 160 km long and deeper than 12–13 m (Fig. 5). Up to 60% of the aqueous volume may be avoided by striped bass because of high temperatures (>22 C) and low oxygen concentrations (≤3.0 ml/liter) (USEPA 1983; Officer et al. 1984). This could force larger striped bass to feed in shallow water, to leave the bay, or both.

Nutrient loading also has been linked to a dramatic decline in submerged aquatic vegetation in shoal areas (Kemp et al. 1983; USEPA 1983). Both young striped bass and their prey inhabit these grass beds (Orth and Heck 1980).

Our correlation analyses show that declines in landings are related to the size of the anoxic (≤0.5 ml/liter O_2) pool during the year of occurrence and 2 years after and to the size of the hypoxic (≤2.0 ml/liter O_2) pool 3 years after the occurrence. This argues for mortality or migration from the bay of harvestable striped bass during the year of occurrence and for some effect on recruitment then, or the next year, that shows up as a decline in landings 2–3 years after the occurrence. Declines in landings also appear to be related to strong flow of the Susquehanna River 4 and 5 years previously. As Officer et al. (1984) suggest, hypoxia in Chesapeake Bay appears to begin with the onset of stratification controlled by the spring freshet from the Susquehanna River. Thus, stronger flows probably contribute to earlier and more intensive hypoxia, the mortality from which is reflected in landings 4 to 5 years later. The indicated effect of low-oxygen water on recruitment 2–5 years after the occurrence is in good biological agreement with Goodyear's (1985) predicted relationship between the juvenile index and landings of striped bass. This, of course, presumes that the effect is on adult spawning stock and that this stock now is depressed to the point of density-dependent recruitment.

The positive influence of the size of the hypoxic pool on the striped bass juvenile index 5 years later could have no biological significance. On the other hand, if intraspecific competition forced by low oxygen contributes to a decline in adult striped bass in the year of hypoxia and 2–3 years later, lower competition of adults with, and predation on, the juveniles could explain the correlation.

The possibility of an oxygen–temperature squeeze during the summer in Chesapeake Bay appears to have existed since at least 1950 (Fig. 5; Table 2). The intensity of the squeeze, based on the volume of anoxic water, has intensified particularly during the 1970s (Fig. 3; Officer et al. 1984). However, data concerning the volume of hypoxic water and temperature do not support a strong case for an increasing oxygen–temperature squeeze with time (Fig. 3; Table 2), although the 2 ml/liter O_2 isopleth was very shallow (7–8 m) in 1977, 1978, and 1980, allowing hypoxic water to encroach much farther onto shoal areas than in previous years except 1961. The trend may not be as apparent in the position of the 2- and 3-ml/liter isopleths because reaeration and the position of the halocline have a greater influence on the position of those isopleths than on the 0.5-ml/liter isopleth (Officer et al. 1984).

The present assessment of the speculative hypothesis concerning nutrient enrichment highlights the problems of distinguishing relationships that are coincidental from those that are meaningful. Meaningful correlations that are not

further tested through use of experimental controls often fail to pass the more rigorous analytical step leading to a cause-and-effect inference. This limitation is inherent in our analysis partly because historical data are not spatially and temporally complete. Some 20 years ago, Mansueti (1962) speculated that striped bass might benefit from nutrient enrichment. Have we reached or passed some nutrient threshold in Chesapeake Bay for striped bass? How might a nutrient enrichment threshold relate to other environmental stresses on striped bass, such as toxic chemicals or a suboptimal climatic regime? These are questions that deserve further careful consideration. In addition, we need better information on fishing pressure on striped bass before a balanced assessment can be made.

There is evidence that nutrient enrichment has occurred in Chesapeake Bay and some of its tidal tributaries. We believe that the evidence for ecological conflicts for striped bass resulting from an oxygen–temperature squeeze is fairly strong, and that the added possibility of intraspecific competition brought on by the loss of benthic habitat is an important consideration. We offer evidence for a nutrient-related loss of submerged aquatic vegetation and concomitant loss of habitat for juvenile striped bass and their prey. Taken together, it is difficult to discount the possible negative influence of nutrient enrichment on striped bass in Chesapeake Bay.

Acknowledgments

We thank Bill Allen and Karin Swartz for producing graphics, Dorothy Szepesi and Juli Tigue for typing the manuscript, and Clement Counts for running the Pearson correlation analyses.

References

Boone, J. G. 1980. Estuarine fish recruitment survey. Maryland Department of Natural Resources, Federal Aid in Fish Restoration Project F-27-R-6, Annapolis, Maryland, USA.

Briggs, P. T., and J. C. O'Connor. 1971. Comparison of shore-zone fishes over naturally vegetated and sand-filled bottoms in Great South Bay. New York Fish and Game Journal 18:15–41.

Carpenter, J. H., and D. G. Cargo. 1957. Oxygen requirement and mortality of the blue crab in Chesapeake Bay. Johns Hopkins University, Chesapeake Bay Institute Reference 57-2, Baltimore, Maryland, USA.

Cooper, J. C., and T. T. Polgar. 1981. Recognition of year-class dominance in striped bass management. Transactions of the American Fisheries Society 110:180–187.

Coutant, C. C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis. Transactions of the American Fisheries Society 114: 31–61.

Goodyear, C. P. 1985. Relationship between reported commercial landings and abundance of young striped bass in Chesapeake Bay, Maryland. Transactions of the American Fisheries Society 114:92–96.

Heinle, D., and six coauthors. 1980. Historical review of water quality and climatic data from Chesapeake Bay with emphasis on effect of enrichment. United States Environmental Protection Agency, Chesapeake Bay Program. National Technical Information Service, PB 82-265-471, Springfield, Virginia, USA.

Kaumeyer, K. R., and E. M. Setzler-Hamilton. 1982. Effects of pollutants and water quality on selected estuarine fish and invertebrates: a review of the literature. Report Submitted to United States Environmental Protection Agency, Chesapeake Bay Program. University of Maryland, Chesapeake Biological Laboratory UMCEES 82-130 CBL, Solomons, Maryland, USA.

Kemp, W. M., W. R. Boynton, R. R. Twilley, J. C. Stevenson, and J. C. Means. 1983. The decline of submerged vascular plants in upper Chesapeake Bay: summary of results concerning possible causes. Marine Technology Society Journal 17:78–89.

Lippson, A. J., editor. 1973. The Chesapeake Bay in Maryland—an atlas of natural resources. Johns Hopkins University Press, Baltimore, Maryland, USA.

Mansueti, R. J. 1962. Effects of civilization on striped bass and other estuarine biota in Chesapeake Bay and tributaries. Proceedings of the Gulf and Caribbean Fisheries Institute 14:110–136.

Mihursky, J. A., W. R. Boynton, E. M. Setzler-Hamilton, K.V. Wood, and T. T. Polgar. 1981. Freshwater influences on striped bass population dynamics. United States Fish and Wildlife Service Biological Services Program FWS-OBS-81-04:149–167.

Newcombe, C. L., and W. A. Horne. 1938. Oxygen-poor waters of the Chesapeake Bay. Science (Washington, D.C.) 88:80–81.

Newcombe, C. L., and A. G. Lang. 1939. The distribution of phosphates in the Chesapeake Bay. Proceedings of the American Philosophical Society 81:393–420.

Officer, C. B., R. B. Biggs, J. L. Taft, L. E. Cronin, M. A. Tyler, and W. R. Boynton. 1984. Chesapeake Bay anoxia: origin, development and significance. Science (Washington, D.C.) 223:22–27.

Orth, R. J. 1977. The importance of sediment stability in seagrass communities. Pages 281–300 *in* B. C. Coull, editor. Ecology of marine benthos. University of South Carolina Press, Columbia, South Carolina, USA.

ORTH, R. J., AND K. L. HECK, JR. 1980. Structural components of eelgrass (*Zostera marina*) meadows in lower Chesapeake Bay—fishes. Estuaries 3: 278–288.

RICHARDS, F. A. 1965. Anoxic basins and fjords. Pages 611–645 *in* J. P. Reiley and G. Skirrow, editors. Chemical oceanography, volume 1. Academic Press, New York, New York, USA.

SETZLER, E. M., AND EIGHT COAUTHORS. 1980. Synopsis of biological data on striped bass, *Morone saxatilis* (Walbaum). NOAA (National Oceanic and Atmospheric Administration) Technical Report NMFS (National Marine Fisheries Service) Circular 433. (Also available as FAO [Food and Agriculture Organization of the United Nations] Fisheries Synopsis 121.)

SCHAEFER, R. H. 1970. Feeding habits of striped bass from the surf waters of Long Island. New York Fish and Game Journal 17:1–17.

TAFT, J. L., E. O. HARTWIG, AND R. LOFTUS. 1980. Seasonal oxygen depletion in Chesapeake Bay. Estuaries 3:242–247.

USEPA (UNITED STATES ENVIRONMENTAL PROTECTION AGENCY). 1983. Chesapeake Bay: a profile of environmental change. Superintendent of Documents, United States Government Printing Office, Washington, D.C., USA.

WAGNER, R. H. 1984. Chesapeake Bay dissolved oxygen study—deep trough. Maryland Department of Natural Resources Report, Annapolis, Maryland, USA.

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.